An Assessment of Ecological Risk to Wild Salmon Systems from Large-scale Mining in the Nushagak and Kvichak Watersheds of the Bristol Bay Basin

October 2010

Developed for:

Developed by:

PREFACE

In 2003, The Nature Conservancy in Alaska identified the Bristol Bay Basin, and in particular the Nushagak and Kvichak watersheds, as a conservation priority under its Wild Salmon Ecosystems program. The Conservancy has been active in the region since the early 1990s.

The Bristol Bay Basin is an intact ecoregion with unimpeded natural ecological processes supporting healthy populations of terrestrial, avian, and aquatic species, including five species of anadromous Pacific salmon. Bristol Bay supports the largest runs of wild sockeye salmon on earth. Historically, the Kvichak River drainage is the world's single most productive sockeye salmon watershed. The Nushagak River watershed is the largest producer of Chinook in the Bristol Bay drainages. In short, these watersheds are the heart of the world's most productive wild salmon nursery.

In January of 2006, the Board of Trustees of The Nature Conservancy in Alaska issued a statement of concern regarding the Nushagak and Kvichak watersheds and the potential impact of mining projects in those watersheds and directed the staff to further evaluate these concerns in conjunction with the organization's conservation efforts in the region. In March 2008, as part of that process, the Salmon Working Group of the Board of Trustees held an internal workshop to better understand the severity, probability and duration of risks posed to the salmon systems of the Nushagak and Kvichak watersheds by large-scale mining operations in the region. Experts in large mine permitting, environmental engineering, salmon habitat, acid mine drainage and risk assessment, guided trustees and staff through a series of presentations, risk assessment exercises, and discussions. As a result, in April 2008 the Board directed staff to develop a risk framework and populate that framework with relevant information to more completely characterize the risks. The following assessment is the result.

As of the date of this assessment, no formal plans have been submitted for permitting large-scale mining in the Nushagak and Kvichak watersheds. Presently, exploration is underway and a preliminary plan for a mine in the Pebble prospect area was released by Northern Dynasty Minerals in 2006 as part of a water withdrawal application to the State of Alaska. For the sake of understanding potential risks of mining development, this analysis uses this preliminary plan as a *scenario* for evaluating risk to local fishery components (e.g., salmon). Use of the plan in this regard is only illustrative and is designed to facilitate assessment of risks from mining development in the region *regardless* of how the Pebble prospect may or may not be developed. Details of any mine plan may change prior to final permitting and a fully permitted mine may change significantly over its life. Risks identified in this scenario and found to be associated with mines regardless of their design (i.e., dewatering, alteration or loss of habitat, road construction, fugitive dust, chemical spills, pipeline spills, episodic and large scale pollution events, acid mine drainage and cumulative effects) apply to any large mining development in the region, whether it be at the Pebble prospect or any of a number of other mining claims currently identified and/or under exploration in the Nushagak and Kvichak watersheds.

The following assessment has been extensively peer reviewed and we would like to thank the following external reviewers, in particular, for their time and advice:

- Mindy Armstead, Ph.D., Potesta and Associates
- Douglas Beltman, Executive Vice President, Stratus Consulting
- John Hedgepeth, Project Manager/Fisheries, Tenera Environmental
- Bill Riley, retired, Environmental Protection Agency
- Thomas Quinn, Ph.D., School of Aquatic and Fishery Sciences, University of Washington

Many others assisted in review and advice at various junctures in the development of this assessment and we thank them for their time and contributions as well. We would also like to take this opportunity to thank the Gordon and Betty Moore Foundation, the Native Village of Ekwok, the Wallace Research Foundation, and the Bristol Bay Regional Seafood Development Association for the financial support that made this assessment possible.

It is important to stress that this risk assessment was designed to provide a science-based perspective of the nature of the potential risks to wild salmon systems and to initiate a greater dialogue about these risks. It is not intended to be exhaustive. For example, so little data is available on the area's groundwater systems that this assessment could not fully characterize risks associated with groundwater; hence, potential instream flow reductions are based solely on surface water data and do not reflect groundwater changes. In addition, this assessment was limited to ecological factors and does not incorporate social, health, economic or cultural considerations that might be relevant to understanding risks associated with large-scale mining in these watersheds. We welcome feedback and discussion about the methodology, assumptions and conclusions in this risk assessment and look forward to the larger public dialogue this may engender.

This assessment is only one component of the Conservancy's effort to understand the biological values in the Nushagak and Kvichak watersheds and the risks posed by mining development. In addition, the Conservancy has undertaken a range of field studies, including fish distribution surveys, water chemistry sampling, macroinvertebrate collection, and hydrologic analysis in and around the Pebble prospect. The results of these studies along with this risk assessment continue to inform the Conservancy's work to protect the biological diversity and abundance of the wild salmon ecosystems of the Bristol Bay region.

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Ecology and Environment, Inc., 2010. *An Assessment of Ecological Risk to Wild Salmon Systems from Large-scale Mining in the Nushagak and Kvichak Watersheds of the Bristol Bay Basin*, Report for The Nature Conservancy, October 2010. 162 pp.

Figure 2. Conceptual Site Model – Physical Stressors

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APPENDIX A

Estimated Pre- and Post-Development Subbasin Monthly Discharges

Table A-1. Estimated Pre- and Post-Development Subbasin Monthly Discharges for North Fork Koktuli River

Pre-Development												
Subbasin	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
Jan	14.8	2.8	1.0	2.6	5.7	6.2	3.0	7.2	8.9	16.6	2.5	71.3
Feb	12.7	2.4	0.8	2.2	4.9	5.3	2.6	6.2	7.6	14.2	2.2	61.1
Mar	12.7	2.4	0.8	2.2	4.9	5.3	2.6	6.2	7.6	14.2	2.2	61.1
Apr	46.7	9.0	3.1	8.1	17.8	19.4	9.5	22.7	27.9	52.1	7.9	224.2
May	201.5	38.7	13.4	34.9	76.9	84.0	41.1	98.1	120.6	224.9	34.3	968.2
Jun	70.0	13.4	4.7	12.1	26.7	29.2	14.3	34.1	41.9	78.1	11.9	336.3
Jul	36.0	6.9	2.4	6.2	13.8	15.0	7.4	17.6	21.6	40.2	6.1	173.3
Aug	42.4	8.1	2.8	7.3	16.2	17.7	8.7	20.7	25.4	47.3	7.2	203.8
Sep	97.5	18.7	6.5	16.9	37.2	40.7	19.9	47.5	58.4	108.9	16.6	468.8
Oct	74.2	14.2	4.9	12.8	28.3	30.9	15.2	36.2	44.4	82.8	12.6	356.7
Nov	74.2	14.2	4.9	12.8	28.3	30.9	15.2	36.2	44.4	82.8	12.6	356.7
Dec	42.4	8.1	2.8	7.3	16.2	17.7	8.7	20.7	25.4	47.3	7.2	203.8
Post-Development												
Jan	14.8	2.8	1.0	2.6	5.7	0.5	3.0	7.2	8.9	16.1	2.5	65.1
Feb	12.7	2.4	0.8	2.2	4.9	0.4	2.6	6.2	7.6	13.8	2.2	55.8
Mar	12.7	2.4	0.8	2.2	4.9	0.4	2.6	6.2	7.6	13.8	2.2	55.8
Apr	46.5	9.0	3.1	8.1	17.8	1.6	9.5	22.7	27.9	50.6	7.9	204.6
May	200.7	38.7	13.4	34.9	76.9	6.8	41.1	97.9	120.6	218.4	34.3	883.6
Jun	69.7	13.4	4.7	12.1	26.7	2.4	14.3	34.0	41.9	75.9	11.9	306.9
Jul	35.9	6.9	2.4	6.2	13.8	1.2	7.4	17.5	21.6	39.1	6.1	158.1
Aug	42.3	8.1	2.8	7.3	16.2	1.4	8.7	20.6	25.4	46.0	7.2	186.0
Sep	97.2	18.7	6.5	16.9	37.2	3.3	19.9	47.4	58.4	105.8	16.6	427.8
Oct	73.9	14.2	4.9	12.8	28.3	2.5	15.2	36.1	44.4	80.5	12.6	325.5
Nov	73.9	14.2	4.9	12.8	28.3	2.5	15.2	36.1	44.4	80.5	12.6	325.5
Dec	42.3	8.1	2.8	7.3	16.2	1.4	8.7	20.6	25.4	46.0	7.2	186.0

Table A-2. Estimated Pre- and Post-Development Subbasin Monthly Discharges for South Fork Koktuli River

Pre-Development													
Subbasin	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**Total**
Jan	9.5	5.7	10.9	11.8	15.6	11.4	9.6	12.5	15.2	13.0	12.8	9.5	137.5
Feb	6.1	3.7	7.0	7.5	10.0	7.3	6.2	8.0	9.7	8.3	8.1	6.1	87.8
Mar	4.6	2.8	5.3	5.7	7.6	5.5	4.7	6.1	7.3	6.3	6.2	4.6	66.6
Apr	7.3	4.4	8.4	9.1	12.0	8.8	7.4	9.6	11.7	10.0	9.8	7.3	105.8
May	61.7	37.0	70.6	76.2	100.7	73.5	62.3	80.9	97.9	83.9	82.4	61.3	888.5
Jun	20.6	12.3	23.5	25.4	33.6	24.5	20.8	27.0	32.6	28.0	27.5	20.4	296.2
Jul	10.3	6.2	11.8	12.7	16.8	12.3	10.4	13.5	16.3	14.0	13.7	10.2	148.1
Aug	11.5	6.9	13.1	14.1	18.7	13.7	11.6	15.0	18.2	15.6	15.3	11.4	165.0
Sep	47.0	28.2	53.8	58.0	76.7	56.0	47.5	61.6	74.6	63.9	62.8	46.7	676.9
Oct	30.8	18.5	35.3	38.1	50.4	36.8	31.2	40.4	49.0	42.0	41.2	30.7	444.2
Nov	23.5	14.1	26.9	29.0	38.4	28.0	23.7	30.8	37.3	32.0	31.4	23.4	338.5
Dec	14.7	8.8	16.8	18.1	24.0	17.5	14.8	19.3	23.3	20.0	19.6	14.6	211.5
Post-Development													
Jan	0.0	0.0	8.4	11.7	15.6	11.4	9.6	12.5	15.2	13.0	12.8	9.5	119.7
Feb	0.0	0.0	5.4	7.5	10.0	7.3	6.2	8.0	9.7	8.3	8.1	6.1	76.4
Mar	0.0	0.0	4.1	5.7	7.6	5.5	4.7	6.1	7.3	6.3	6.2	4.6	58.0
Apr	0.0	0.0	6.5	9.0	12.0	8.7	7.4	9.6	11.7	10.0	9.8	7.3	92.0
May	0.0	0.0	54.3	75.8	100.7	73.5	62.3	80.9	97.9	84.0	82.4	61.3	773.2
Jun	0.0	0.0	18.1	25.3	33.6	24.5	20.8	27.0	32.6	28.0	27.5	20.4	257.7
Jul	0.0	0.0	9.1	12.6	16.8	12.2	10.4	13.5	16.3	14.0	13.7	10.2	128.9
Aug	0.0	0.0	10.1	14.1	18.7	13.6	11.6	15.0	18.2	15.6	15.3	11.4	143.6
Sep	0.0	0.0	41.4	57.7	76.8	56.0	47.5	61.6	74.6	64.0	62.8	46.7	589.1
Oct	0.0	0.0	27.2	37.9	50.4	36.7	31.2	40.4	49.0	42.0	41.2	30.6	386.6
Nov	0.0	0.0	20.7	28.9	38.4	28.0	23.8	30.8	37.3	32.0	31.4	23.3	294.6
Dec	0.0	0.0	12.9	18.0	24.0	17.5	14.8	19.3	23.3	20.0	19.6	14.6	184.1

Table A-3. Estimated Pre- and Post-Development Subbasin MonthlyDischarges for Upper TalarikCreek

Pre-Development																
Subbasin	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**Total**
Jan	2.1	15.3	5.3	4.2	15.2	7.0	3.2	9.1	25.1	3.7	7.8	5.2	4.1	4.6	8.6	120.4
Feb	1.2	8.9	3.1	2.4	8.8	4.1	1.9	5.3	14.6	2.2	4.6	3.0	2.4	2.7	5.0	70.3
Mar	0.9	6.4	2.2	1.7	6.3	2.9	1.3	3.8	10.5	1.5	3.3	2.2	1.7	1.9	3.6	50.2
Apr	5.4	39.5	13.7	10.8	39.2	18.2	8.3	23.6	64.8	9.5	20.2	13.4	10.6	11.8	22.1	311.2
May	8.8	63.7	22.2	17.4	63.2	29.3	13.4	38.1	104.6	15.4	32.5	21.6	17.1	19.1	35.7	501.9
Jun	4.2	30.6	10.6	8.4	30.3	14.1	6.4	18.3	50.2	7.4	15.6	10.3	8.2	9.2	17.1	240.9
Jul	3.2	22.9	8.0	6.3	22.7	10.5	4.8	13.7	37.6	5.5	11.7	7.8	6.2	6.9	12.9	180.7
Aug	3.0	21.7	7.5	5.9	21.5	10.0	4.5	13.0	35.5	5.2	11.1	7.3	5.8	6.5	12.1	170.6
Sep	8.1	58.6	20.4	16.0	58.1	27.0	12.3	35.1	96.2	14.2	29.9	19.8	15.7	17.6	32.8	461.7
Oct	6.7	48.4	16.8	13.2	48.0	22.3	10.1	29.0	79.5	11.7	24.7	16.4	13.0	14.5	27.1	381.4
Nov	6.1	44.6	15.5	12.2	44.2	20.5	9.3	26.7	73.2	10.8	22.8	15.1	12.0	13.4	25.0	351.3
Dec	3.3	24.2	8.4	6.6	24.0	11.1	5.1	14.5	39.7	5.9	12.4	8.2	6.5	7.3	13.6	190.7
Post-Development																
Jan	2.1	15.3	5.3	4.2	3.0	7.0	3.2	9.1	25.1	3.7	7.8	5.2	4.1	4.6	8.6	108.2
Feb	1.2	8.9	3.1	2.4	1.7	4.1	1.9	5.3	14.6	2.2	4.5	3.0	2.4	2.7	5.0	63.1
Mar	0.9	6.4	2.2	1.7	1.2	2.9	1.3	3.8	10.5	1.5	3.2	2.2	1.7	1.9	3.6	45.1
Apr	5.4	39.5	13.7	10.8	7.7	18.0	8.3	23.6	64.8	9.5	20.1	13.4	10.6	11.8	22.1	279.5
May	8.8	63.7	22.2	17.4	12.4	29.0	13.3	38.1	104.6	15.4	32.5	21.6	17.1	19.1	35.7	450.8
Jun	4.2	30.6	10.6	8.4	5.9	13.9	6.4	18.3	50.2	7.4	15.6	10.3	8.2	9.2	17.1	216.4
Jul	3.2	22.9	8.0	6.3	4.5	10.4	4.8	13.7	37.6	5.5	11.7	7.8	6.2	6.9	12.9	162.3
Aug	3.0	21.7	7.5	5.9	4.2	9.9	4.5	13.0	35.6	5.2	11.0	7.3	5.8	6.5	12.1	153.3
Sep	8.1	58.6	20.4	16.0	11.4	26.7	12.3	35.1	96.2	14.2	29.9	19.8	15.7	17.6	32.9	414.8
Oct	6.7	48.4	16.8	13.2	9.4	22.0	10.1	29.0	79.5	11.7	24.7	16.4	13.0	14.5	27.1	342.6
Nov	6.1	44.6	15.5	12.2	8.7	20.3	9.3	26.7	73.2	10.8	22.7	15.1	12.0	13.4	25.0	315.6
Dec	3.3	24.2	8.4	6.6	4.7	11.0	5.1	14.5	39.7	5.8	12.3	8.2	6.5	7.3	13.6	171.3

APPENDIX B

Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon

Table B-1. Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon[1]

Variable Number	Habitat Variable Description	Life Stage Affected	Maximum Suitability Index Description
Coho Salmon			
V_1	Maximum temperature during upstream migration	Adult	up to 11 degrees C
V_2	Minimum dissolved oxygen during upstream migration		> 6.5 mg/l
V_3	Maximum temperature from spawning to fry emergence	Spawning/embryo /alevin	Between 5 degrees C and 12 degrees C
V_4	Minimum dissolved oxygen saturation levels from spawning to fry emergence		80%
V_5	Substrate composition in riffle/run areas		>50% gravel and rubble <u>or</u> <5% fines (e.g., particles < 6mm)
V_6	Maximum temperature during rearing (parr)	Parr	9 – 13 degrees C
V_7	Minimum dissolved oxygen during rearing (parr)		up to 8 mg/l
V_8	Percent canopy over rearing stream		50% to 75%
V_9	Riparian vegetation index in summer		150 and above (based on formula where ≥ 75% deciduous shrubs and trees rates excellent)
V_{10}	Percent pools during summer low flow periods		Between 45% and 60%
V_{11}	Proportion of pools during summer low flow period that are 10-80 m^3 or 50-250 m^2, and have sufficient riparian canopy cover		Above 75%
V_{12}	Percent instream and bank cover during summer low flow period		Above 35%
V_{13}	Percent total area with quiet backwaters and deep (≥ 45 cm) pools with good in water habitat.		Above 30%
V_{14}	Maximum temperature during (A) winter in rearing streams and (B) spring-early summer in streams where seaward smolt migration occurs	Smolt	(A) – not greater than 8 degrees C (B) – not greater than 12 degrees C
V_{15}	Minimum dissolved oxygen during spring-early summer period in streams where seaward migration occurs		Not less than 8 mg/l

Table B-1. Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon[1]

Variable Number	Habitat Variable Description	Life Stage Affected	Maximum Suitability Index Description
Chinook Salmon			
V_1	Annual maximum or minimum pH as measured in summer and fall (using lowest SI value).	Adult	6.5 to 8.0
V_2	Maximum temperature during warmest periods when adults or juveniles present	Adult, Juvenile	A = prespawning adults – 7 to 12 degrees C B = juveniles – 12 to 18 degrees C
V_3	Minimum dissolved oxygen levels during egg and pre-emergent yolk sac fry period; and during occupation by adults and juveniles	Embryo, Juvenile	8 mg/l at ≤ 5 degrees C 12 mg/l at >10 degrees C
V_4	Percent pools during late growing season / low water period	Adult, Juvenile	40% to 60%
V_5	Pool class rating during the late growing season / low flow period		Variable based on percentage of pools in habitat
V_6	Maximum or minimum temperature at beginning and end of first month of spawning of late summer or fall spawning stocks. (using lowest SI value) [minimum temperature must remain ≥ 4.5 degrees C for ≥ 3 ½ weeks after fertilization	Spawning/embryo	4.5 to 13 degrees C
V_7	Maximum or minimum temperature at beginning and end of embryo incubation period. Use the temperature that yields the lowest SI. [applicable to spring spawning stocks only]	Embryo	6.0 to 14 degrees C
V_8	Percentage of spawning gravel in two classes	Spawning, Embryo, Fry	Based on spatial assessment of gravel types
V_9	Average water column velocity (cm/s) over areas of spawning gravel used by Chinook salmon		Velocity of 30 cm/s to 90 cm/s
V_{10}	Average percentage of fines in spawning gravel – includes silts (≤0.8mm) and sand (0.8 to 30mm)		~ 5% or less

Table B-1. Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon[1]

Variable Number	Habitat Variable Description	Life Stage Affected	Maximum Suitability Index Description
V_{11}	Average annual base flow during the late summer to later winter low-flow period as percentage of the average daily flow. For embryo and pre-emergent fry use the average and low flows that occur during intergravel occupation period.	Embryo, Juvenile	50%
V_{12}	Average annual peak flow as multiple of average annual daily flow	Embryo, Standing crop	Multiple of 2 to 3
V_{13}	Predominant (≥50%) substrate type in riffle-run areas for food production indicator – for juvenile rearing and upstream areas.	Juvenile, Standing crop	Rubble or small boulders dominate; limited amounts of gravel, large boulders or slab rock present; no fines.
V_{14}	Average percentage of fines (<3 mm) in riffle-run areas		10% or less
V_{15}	Nitrate-nitrogen (mg/l) in late summer after spawner die off		0.15 – 0.25 mg/l
V_{16}	Percentage of stream area providing escape cover – late summer-fall average to low flow period at depths ≥ 15 cm and with bottom velocities ≤ 40 cm/s.	Juvenile	20 – 50 %
V_{17}	Percentage of stream area with 10 to 40 cm average sized boulders. [only for juveniles that overwinter in freshwater]		15 – 25 %
Chum Salmon			
V_1	Maximum temperature during upstream migration	Spawning Adult	Between 8 degrees C and 12 degrees C
V_2	Minimum dissolved oxygen during upstream migration		> 6.5 mg/l
V_3	Extreme intragravel temperatures from spawning to fry emergence	Embryo, Fry	Maximum – 7.2 to 12.8 degrees C Minimum – 6 to 8 degrees C
V_4	Minimum dissolved oxygen concentration from spawning to fry emergence		6 mg/l
V_5	Substrate composition within riffle-run areas. A: percent gravel substrate 10-100mm diameter B: percent fines (< 6 mm)	Spawning Adult, Embryo, Fry	A: ≥ 60% B: <10% fines

Table B-1. Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon[1]

Variable Number	Habitat Variable Description	Life Stage Affected	Maximum Suitability Index Description
V_6	Stream discharge pattern from egg deposition to downstream migration of fry	Embryo, Alevins	Best condition is stable streamflow, < 100-fold difference between extreme average daily stream discharges; stream channel stable, with little shifting.
V_7	Mean intragravel salinity for embryos and alevins	Embryo	< 4 ppt
V_8	Temperature extremes during rearing and downstream migration of fry. A: maximum B: minimum	Smolts	A: 12 degrees C B: 7 degrees C
V_9	Minimum dissolved oxygen during rearing and downstream migration of fry	Fry	8 mg/l
Pink Salmon			
V_1	Annual maximal or minimal pH (summer to fall period)	Adult, Juvenile	6.5 to 8.0
V_2	Maximal or minimal water temperature during the adult upstream migration and spawning period	Spawning Adult	8 degrees C to 13 degrees C
V_3	Average size range of substrate particle used for spawning	Spawning Adult, Embryo, Fry	1 to 5 cm
V_4	Percent fines (<0.3 cm) for survival of embryos and emergent fry	Embryo, Fry	6%
V_5	Average water velocity for spawning and embryo incubation	Spawning Adult, Embryo	40 cm/s
V_6	Minimal dissolved oxygen during egg incubation and pre-emergent yolk sac fry period	Embryo	8 mg/l
V_7	Maximal or minimal water temperature during early embryo development period	Embryo, Fry	7.5 degrees C to 12.5 degrees C
V_8	Maximal salinity during embryo development	Embryo	30 ppt
V_9	Average base flow during embryo incubation period (as percentage of average daily flow during spawning)		50%

Table B-1. Habitat Suitability Index Variables, Description, and Associated Life Stage for Coho, Chinook, Chum, and Pink Salmon[1]

Variable Number	Habitat Variable Description	Life Stage Affected	Maximum Suitability Index Description
V_{10}	Peak flow during incubation period (as multiple of average base flow)	Embryo	2 to 5
V_{11}	Maximum temperature during the period of seawater migration	Fry	2.5 degrees C to 17 degrees C

1 Habitat Variables from USFWS Habitat Suitability Index Models: Coho – McMahon, 1983; Chinook – Raleigh, Miller and Nelson, 1986; Chum – Hale, McMahon and Nelson, 1985; Pink – Raleigh and Nelson, 1985.

APPENDIX C

Alaska's Impaired Waters – 2008

Table C-1
ALASKA's IMPAIRED WATERS – 2008

Impaired Water body Categories:

Category 4a – Impaired water with a final/approved TMDL
Category 5 – Impaired water, Section 303(d) list, require TMDL

Within the tables waters are listed by region - -Interior, Southcentral, Southeast – and alphabetically.

Region	Category	Alaska ID #	Water body	Location	Area of Concern	Water Quality Standard	Pollutant Parameters	Pollutant Sources
Category 4a Waterbodies – Impaired but not needing a TMDL, TMDL has been completed								
IN	Category 4a	40402-001	Birch Creek Drainage:-Upper Birch Creek; Eagle Creek; Golddust Creek	North of Fairbanks	N/A	Turbidity	Turbidity	Placer Mining
SE	Category 4a	10203-005	Granite Creek	Sitka	N/A	Turbidity Sediment	Turbidity, Sediment	Gravel Mining
SE	Category 4a	10301-001	Lemon Creek	Juneau	N/A	Turbidity Sediment	Turbidity, Sediment	Urban Runoff, Gravel Mining
Category 5 Section 303(d) Listed Waterbodies – Impaired by pollutant(s) for one or more designated uses and requiring a TMDL ;Clean Water Act Section 303(d) Listed Waters								
IN	Category 5 Section 303(d) listed	20502-101	Caribou Creek	Denali National Park	16.1 miles	Turbidity	Turbidity	Mining
IN	Category 5 Section 303(d) listed	40402-010	Crooked Creek Bonanza Crooked Deadwood Ketchem Mammoth Mastodon Porcupine	North of Fairbanks	77 miles	Turbidity	Turbidity	Placer Mining
IN	Category 5 Section 303(d) listed	40402-010	Crooked Creek Bonanza Crooked Deadwood Ketchem Mammoth Mastodon Porcupine	North of Fairbanks	77 miles	Turbidity	Turbidity	Placer Mining

Region	Category	Alaska ID #	Water body	Location	Area of Concern	Water Quality Standard	Pollutant Parameters	Pollutant Sources
IN	Category 5 Section 303(d) listed	40509-001	Goldstream Creek	Fairbanks	70 miles	Turbidity	Turbidity	Placer Mining
IN	Category 5 Section 303(d) listed	40510-101	Slate Creek	Denali National Park	2.5 miles	Turbidity	Turbidity	Mining
SE	Category 5 Section 303(d) listed	10203-002	Katlian River	N. of Sitka, Baranof Island	4.5 miles	Sediment, Turbidity	Sediment, Turbidity	Timber Harvest
SE	Category 5 Section 303(d) listed	10203-602	Klag Bay	West Chichagof Island	1.25 acres	Toxic & Other Deleterious Organic and Inorganic Substances	Metals	Mining
SE	Category 5 Section 303(d) listed	10203-001	Nakwasina River	Baranof Island, Sitka	8 miles	Sediment, Turbidity	Sediment, Turbidity	Timber Harvest
SE	Category 5 Section 303(d) listed	10303-004	Pullen Creek (Lower Mile)	Skagway	Lower mile of Pullen Creek	Toxic & Other Deleterious Organic and Inorganic Substances	Metals	Industrial
SE	Category 5 Section 303(d) listed	10303-601	Skagway Harbor	Skagway	1.0 acre	Toxic & Other Deleterious Organic and Inorganic Substances	Metals	Industrial

APPENDIX D

Factors Affecting Contaminant Transfer to Environmental Groundwater, Surface Water, and Soil

Table D-1. Factors Affecting Contaminant Transfer to Environmental Groundwater, Surface Water and Soil

Transport Mechanism	Factors Affecting Transport: Chemical-Specific Considerations	Factors Affecting Transport: Site-Specific Considerations
Groundwater		
Movement within and across aquifers and to surface water	• Density (more or less dense than water) • Water solubility • K_{OC} (organic carbon partition coefficient)	• Site hydrogeology • Precipitation • Infiltration rate • Porosity • Hydraulic conductivity • Groundwater flow direction • Depth to aquifer • Groundwater/surface water recharge and discharge zones • Presence of other compounds • Soil type • Geochemistry of site soils and aquifers • Presence and condition of wells (well location, depth, and use; casing material and construction; pumping rate) • Conduits, sewers
Volatilization (to soil gas, ambient air, and indoor air)	• Water solubility • Vapor pressure • Henry's Law Constant • Diffusivity	• Depth to water table • Soil type and cover • Climatologic conditions • Contaminant concentrations • Properties of buildings • Porosity and permeability of soils and shallow geologic materials
Adsorption to soil or precipitation out of solution	• Water solubility • K_{OW} (octanol/water partition coefficient) • K_{OC}	• Presence of natural carbon compounds • Soil type, temperature, and chemistry • Presence of other compounds
Biologic uptake	• K_{OW}	• Groundwater use for irrigation and livestock watering
Soil (Surface and Subsurface) and Sediment		
Runoff (soil erosion)	• Water solubility • K_{OC}	• Presence of plants • Soil type and chemistry • Precipitation rate • Configuration of land and surface condition

Transport Mechanism	Factors Affecting Transport	
	Chemical-Specific Considerations	Site-Specific Considerations
Leaching	• Water solubility • K_{OC}	• Soil type • Soil porosity and permeability • Soil chemistry (especially acid/base) • Cation exchange capacity • Organic carbon content
Volatilization	• Vapor pressure • Henry's Law Constant	• Physical properties of soil • Chemical properties of soil • Climatologic conditions
Biologic uptake	• Bioconcentration factor • Bioavailability	• Soil properties • Contaminant concentration
Surface Water		
Overland flow (via natural drainage or man-made channels)	• Water solubility • K_{OC}	• Precipitation (amount, frequency, duration) • Infiltration rate • Topography (especially gradients and sink holes) • Vegetative cover and land use • Soil/sediment type and chemistry • Use as water supply intake areas • Location, width, and depth of channel; velocity; dilution factors; direction of flow • Floodplains • Point and nonpoint source discharge areas
Volatilization	• Water solubility • Vapor pressure • Henry's law constant	• Climatic conditions • Surface area • Contaminant concentration
Hydrologic connection between surface water and groundwater	• Density	• Groundwater/surface water recharge and discharge • Stream bed permeability • Soil type and chemistry • Geology (especially Karst conditions)
Adsorption to soil particles and sedimentation (of suspended and precipitated particles)	• Water solubility • K_{OW} • K_{OC} • Density	• Particle size and density • Geochemistry of soils/sediments • Organic carbon content of soils/sediment

Transport Mechanism	Factors Affecting Transport	
	Chemical-Specific Considerations	Site-Specific Considerations
Biota		
Biologic uptake	• K_{OW} • Bioconcentration factor	• Chemical concentration • Presence of fish, plants, and other animals
Bioaccumulation	• K_{OW} • Persistence/half-life	• Presence of plants and animals • Consumption rate
Migration	• NA	• Commercial activities (farming, aquaculture, livestock, dairies) • Sport activities (hunting, fishing) • Migratory species
Vapor sorption	• NA	• Soil type • Plant species
Root uptake	• NA	• Contaminant depth • Soil moisture • Plant species

APPENDIX E

Historic Information on World-Wide Dam Failures

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
May 14, 2009	Huayuan County, Xiangxi Autonomous Prefecture, Hunan Province, China	?	manganese	tailings dam failure (capacity: 50,000 cubic metres)	?	The landslide set off by the tailings dam failure destroyed a home, killing three and injuring four people.
Dec. 22, 2008	Kingston fossil plant, Harriman, Tennessee, USA	Tennessee Valley Authority	coal ash	retention wall failure	Release of 5.4 million cubic yards [4.1 million cubic metres] of ashy slurry	The ash slide covered 400 acres [1.6 square kilometres] as deep as 6 feet [1.83 metres]. The wave of ash and mud toppled power lines, covered Swan Pond Road and ruptured a gas line. It damaged 12 homes, and one person had to be rescued, though no one was seriously hurt.
Sep. 8, 2008	Taoshi, Linfen City, Xiangfen county, Shanxi province, China	Tashan mining company	iron	Collapse of a waste-product reservoir at an illegal mine during rainfall	?	A mudslide several metres high buried a market, several homes and a three-storey building. At least 254 people are dead and 35 injured.
Nov. 6, 2006	Nchanga, Chingola, Zambia	Konkola Copper Mines Plc (KCM) (51% Vedanta Resources plc)	copper	failure of tailings slurry pipeline from Nchanga tailings leaching plant to Muntimpa tailings dumps	?	Release of highly acidic tailings into Kafue river; high concentrations of copper, manganese, cobalt in river water; drinking water supply of downstream communities shut down

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
April 30, 2006	near Miliang, Zhen'an County, Shangluo, Shaanxi Province, China	Zhen'an County Gold Mining Co. Ltd.	gold	tailings dam failure during sixth upraising of dam	?	The landslide buried about 40 rooms of nine households, leaving 17 residents missing. Five injured people were taken to hospital. More than 130 local residents have been evacuated. Toxic potassium cyanide was released into the Huashui river, contaminating it approx. 5 km downstream.
April 14, 2005	Bangs Lake, Jackson County, Mississippi, USA	Mississippi Phosphates Corp.	phosphate	phosphogypsum stack failure, because the company was trying to increase the capacity of the pond at a faster rate than normal, according to Officials with the Mississippi Department of Environmental Quality (the company has blamed the spill on unusually heavy rainfall, though)	approx. 17 million gallons of acidic liquid (64,350 m3)	liquid poured into adjacent marsh lands, causing vegetation to die
2004, Nov. 30	Pinchi Lake, British Columbia, Canada	Teck Cominco Ltd.	mercury	tailings dam (100-metres long and 12-metres high) collapses during reclamation work	6,000 to 8,000 m3 of rock, dirt and waste water	tailings spilled into 5,500 ha Pinchi Lake

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
2004, Sep. 5	Riverview, Florida, USA	Cargill Crop Nutrition	phosphate	a dike at the top of a 100-foot-high gypsum stack holding 150-million gallons of polluted water broke after waves driven by Hurricane Frances bashed the dike's southwest corner	60 million gallons (227,000 m3) of acidic liquid	liquid spilled into Archie Creek that leads to Hillsborough Bay
2004, May 22	Partizansk, Primorski Krai, Russia	Dalenergo	coal ash	A ring dike, enclosing an area of roughly 1 km^2 and holding roughly 20 million cubic meters of coal ash, broke. The break left a hole roughly 50 meter wide in the dam.	approximately 160,000 cubic meters of ash	The ash flowed through a drainage canal into a tributary to the Partizanskaya River which empties in to Nahodka Bay in Primorski Krai (east of Vladivostok). For details download Sept. 2004 report (PDF) by Paul Robinson, SRIC
2004, March 20	Malvési, Aude, France	Comurhex (Cogéma/Areva)	decantation and evaporation pond of uranium conversion plant	dam failure after heavy rain in preceding year (view details)	30,000 cubic metres of liquid and slurries	release led to elevated nitrate concentrations of up to 170 mg/L in the canal of Tauran for several weeks
2003, Oct. 3	Cerro Negro, Petorca prov., Quinta region, Chile	Cia Minera Cerro Negro	copper	tailings dam failure	50,000 tonnes of tailings	tailings flowed 20 kilometers downstream the río La Ligua

Table E-1. Historic Information on World-Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
2002, Aug. 27 / Sep. 11	San Marcelino, Zambales, Philippines	Dizon Copper Silver Mines, Inc.		overflow and spillway failure of two abandoned tailings dams after heavy rain (view details)	?	Aug. 27: some tailings spilled into Mapanuepe Lake and eventually into the Sto. Tomas River Sep. 11: low lying villages flooded with mine waste; 250 families evacuated; nobody reported hurt so far
2001, Jun. 22	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil	Mineração Rio Verde Ltda	iron	mine waste dam failure (view details)	?	tailings wave traveled at least 6 km, killing at least two mine workers, three more workers are missing
2000, Oct. 18	Nandan county, Guangxi province, China	?	?	tailings dam failure	?	at least 15 people killed, 100 missing; more than 100 houses destroyed
2000, Oct. 11	Inez, Martin County, Kentucky, USA	Martin County Coal Corporation (100% A.T. Massey Coal Company, Inc. , Richmond, VA (100% Fluor Corp.))	coal	tailings dam failure from collapse of an underground mine beneath the slurry impoundment (view details)	250 million gallons (950,000 m3) of coal waste slurry released into local streams	About 75 miles (120 km) of rivers and streams turned an iridescent black, causing a fish kill along the Tug Fork of the Big Sandy River and some of its tributaries. Towns along the Tug were forced to turn off their drinking water intakes.

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
2000, Sep. 8	Aitik mine, Gällivare, Sweden	Boliden Ltd.	copper	tailings dam failure from insufficient perviousness of filter drain (view details)	release of 2.5 million m3 of liquid into an adjacent settling pond, subsequent release of 1.5 million m3 of water (carrying some residual slurry) from the settling pond into the environment	
2000, Mar. 10	Borsa, Romania	Remin S.A.		tailings dam failure after heavy rain	22,000 t of heavy-metal contaminated tailings	contamination of the Vaser stream, tributary of the Tisza River. View Romanian Govt. report · UNEP report (527k PDF)
2000, Jan. 30	Baia Mare, Romania	Aurul S.A. (Esmeralda Exploration, Australia (50%), Remin S.A. (44.8%))	gold recovery from old tailings	tailings dam crest failure after overflow caused from heavy rain and melting snow (view details)	100,000 m^3 of cyanide-contaminated liquid	contamination of the Somes/Szamos stream, tributary of the Tisza River, killing tonnes of fish and poisoning the drinking water of more than 2 million people in Hungary
1999, Apr. 26	Placer, Surigao del Norte, Philippines	Manila Mining Corp. (MMC)	gold	tailings spill from damaged concrete pipe	700,000 tonnes of cyanide tailings	17 homes buried, 51 hectares of riceland swamped
1998, Dec. 31	Huelva, Spain	Fertiberia, Foret	phosphate	dam failure during storm (view details)	50,000 m3 of acidic and toxic water	

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1998, Apr. 25	Los Frailes, Aznalcóllar, Spain	Boliden Ltd., Canada	zinc, lead, copper, silver	dam failure from foundation failure (view details)	4-5 million m3 of toxic water and slurry	thousands of hectares of farmland covered with slurry
1997, Dec. 7	Mulberry Phosphate, Polk County, Florida, USA	Mulberry Phosphates, Inc.	phosphate	phosphogypsum stack failure	200,000 m3 of phosphogypsum process water	biota in the Alafia River eliminated
1997, Oct. 22	Pinto Valley, Arizona, USA	BHP Copper	copper	tailings dam slope failure	230,000 m3 of tailings and mine rock	tailings flow covers 16 hectares
1996, Nov. 12	Amatista, Nazca, Peru	?	?	liquefaction failure of upstream-type tailings dam during earthquake	more than 300,000 m3 of tailings	flow runout of about 600 meters, spill into river, croplands contaminated
1996, Aug. 29	El Porco, Bolivia	Comsur (62%), Rio Tinto (33%)	zinc, lead, silver	dam failure	400,000 tonnes	300 km of Pilcomayo river contaminated
1996, Mar. 24	Marcopper, Marinduque Island, Philippines	Placer Dome Inc., Canada (40%)	copper	Loss of tailings from storage pit through old drainage tunnel	1.6 million m3	Evacuation of 1200 residents, 18 km of river channel filled with tailings, US$ 80 million damage
1995, Dec.	Golden Cross, New Zealand	Coeur d'Alène, Idaho, USA	gold	Dam movement of dam containing 3 million tonnes of tailings (continuing) (view details)	Nil (so far)	Nil (so far)

Table E-1. Historic Information on World-Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1995, Sep. 2	Placer, Surigao del Norte, Philippines	Manila Mining Corp.	gold	Dam foundation failure	50,000 m3	12 people killed, coastal pollution
1995, Aug. 19	Omai, Guyana	Cambior Inc., Canada (65%), Golden Star Resources Inc., Colorado, USA (30%)	gold	tailings dam failure from internal dam erosion (preliminary report on technical causation)	4.2 million m3 of cyanide slurry	80 km of Essequibo River declared environmental disaster zone (view details)
1994, Nov. 19	Hopewell Mine, Hillsborough County, Florida, USA	IMC-Agrico	phosphate	dam failure	Nearly 1.9 million m3 of water from a clay settling pond	spill into nearby wetlands and the Alafia River, Keysville flooded
1994, Oct. 2	Payne Creek Mine, Polk County, Florida, USA	IMC-Agrico	phosphate	dam failure	6.8 million m3 of water from a clay settling pond	majority of spill contained on adjacent mining area; 500,000 m3 released into Hickey Branch, a tributary of Payne Creek
1994, Oct.	Fort Meade, Florida, USA	Cargill	phosphate	?	76,000 m3 of water	spill into Peace River near Fort Meade
1994, June	IMC-Agrico, Florida, USA	IMC-Agrico	phosphate	Sinkhole opens in phosphogypsum stake	?	Release of gympsum and water into groundwater
1994, Feb. 22	Harmony, Merriespruit, South Africa	Harmony Gold Mines	gold	Dam wall breach following heavy rain	600,000 m3	tailings traveled 4 km downstream, 17 people killed, extensive damage to residential township

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1994, Feb. 14	Olympic Dam, Roxby Downs, South Australia	WMC Ltd.	copper, uranium	leakage of tailings dam during 2 years or more	release of up to 5 million m3 of contaminated water into subsoil	?
1993, Oct.	Gibsonton, Florida, USA	Cargill	phosphate	?	?	Fish killed when acidic water spilled into Archie Creek
1993	Marsa, Peru	Marsa Mining Corp.	gold	dam failure from overtopping	?	6 people killed
1992, Mar. 1	Maritsa Istok 1, near Stara Zagora, Bulgaria	?	ash/cinder	dam failure from inundation of the beach	500,000 m3	?
1992, Jan.	No.2 tailings pond, Padcal, Luzon, Philippines	Philex Mining Corp.	copper	Collapse of dam wall (foundation failure)	80 million tonnes	?
1991, Aug. 23	Sullivan mine, Kimberley, British Columbia, Canada	Cominco Ltd	lead/zinc	dam failure (liquefaction in old tailings foundation during construction of incremental raise)	75,000 m3	the slided material was contained in an adjacent pond
1989, Aug. 25	Stancil, Perryville, Maryland, USA	?	sand and gravel	dam failure during capping of the tailings after heavy rain	38,000 m3	tailings flowside covered 5000 m2
1988, Apr. 30	Jinduicheng, Shaanxi province, China	?	molybdenum	breach of dam wall (spillway blockage caused pond level to rise too high)	700,000 m3	approx. 20 people killed

Table E-1. Historic Information on World-Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1988, Jan. 19	Tennessee Consolidated No.1, Grays Creek, TN, USA	Tennessee Consolidated Coal Co.	coal	dam wall failure from internal erosion, caused from failure of an abandoned outlet pipe	250,000 m3	?
1988	Riverview, Florida, USA	Gardinier (now Cargill)	phosphate	?	acidic spill	Thousands of fish killed at mouth of Alafia River
1987, April 8	Montcoal No.7, Raleigh County, West Virginia, USA	Peabody Coal Co. (now Peabody Energy)	coal	dam failure after spillway pipe breach	87,000 cubic meters of water and slurry	tailings flow 80 km downstream
1986, May	Itabirito, Minas Gerais, Brazil	Itaminos Comercio de Minerios	?	dam wall burst	100,000 tonnes	tailings flow 12 km downstream
1986	Huangmeishan, China	?	iron	dam failure from seepage/slope instability	?	19 people killed
1985, July 19	Stava, Trento, Italy	Prealpi Mineraia	fluorite	dam failure, caused from insufficient safety margins and inadequate decant pipe construction (view details)	200,000 m3	tailings flow 4.2 km downstream at 90 km/h; 268 people killed, 62 buildings destroyed (view details)
1985, Mar. 3	Veta de Agua No.1, Chile	?	copper	dam wall failure, due to liquefaction during earthquake	280,000 m3	tailings flow 5 km downstream
1985, Mar. 3	Cerro Negro No.4, Chile	Cia Minera Cerro Negro	copper	dam wall failure, due to liquefaction during earthquake	500,000 m3	tailings flow 8 km downstream

Table E-1. Historic Information on World-Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1985	Olinghouse, Wadsworth, Nevada, USA	Olinghouse Mining Co.	gold	embankment collapse from saturation	25,000 m3	tailings flow 1.5 km downstream
1982, Nov. 8	Sipalay, Negros Occidental, Philippines	Marinduque Mining and Industrial Corp.	copper	dam failure, due to slippage of foundations on clayey soils	28 million tonnes	Widespread inundation of agricultural land up to 1.5 m high
1981, Dec. 18	Ages, Harlan County, Kentucky, USA	Eastover Mining Co.	coal	dam failure after heavy rain	96,000 m3 coal refuse slurry	the slurry wave traveled the Left Fork of Ages Creek 1.3 km downstream, 1 person was killed, 3 homes destroyed, 30 homes damaged, fish kill in Clover Fork of the Cumberland River
1981, Jan. 20	Balka Chuficheva, Lebedinsky, Russia	?	iron	dam failure	3.5 million m3	tailings travel distance 1.3 km
1980, Oct. 13	Tyrone, New Mexico, USA	Phelps Dodge	copper	dam wall breach, due to rapid increase in dam wall height, causing high internal pore pressure	2 million m3	tailings flow 8 km downstream and inundate farmland
1979, July 16	Church Rock, New Mexico, USA	United Nuclear	uranium	dam wall breach, due to differential foundation settlement	370,000 m3 of radioactive water, 1,000 tonnes of contaminated sediment	Contamination of Rio Puerco sediments up to 110 km downstream

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1979 or earlier	(unidentified), British Columbia, Canada	?	?	piping in the sand beach of the tailings dam	40,000 m3 of ponded water	considerable property damage
1978, Jan. 31	Arcturus, Zimbabwe	Corsyn Consolidated Mines	gold	slurry overflow after continuous rain over several days	30,000 tonnes	1 person killed, extensive siltation to waterway and adjoining rough pasture
1978, Jan. 14	Mochikoshi No.1, Japan	?	gold	dam failure, due to liquefaction during earthquake	80,000 m3	1 person killed, tailings flow 7-8 km downstream
1977, Feb. 1	Homestake, Milan, New Mexico, USA	Homestake Mining Company	uranium	dam failure, due to rupture of plugged slurry pipeline	30,000 m3	no impacts outside the mine site
1976, Mar. 1	Zlevoto, Yugoslavia	?	lead, zinc	dam failure, due to high phreatic surface and seepage breakout on the embankment face	300,000 m3	tailings flow reached and polluted nearby river
1975, June	Silverton, Colorado, USA	?	(metal)	dam failure	116,000 tonnes	tailings flow slide polluted nearly 100 miles (160 km) of the Animas river and its tributaries; severe property damage; no injuries
1975, Apr.	Madjarevo, Bulgaria	?	lead, zinc, gold	rising of tailings above design level caused overloading of the decant tower and collectors	250,000 m3	?

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1975	Mike Horse, Montana, USA	?	lead, zinc	dam failure after heavy rain	150,000 m3	?
1974, Nov. 11	Bafokeng, South Africa	?	platinum	embankment failure by concentrated seepage and piping through cracks	3 million m3	12 people killed in a mine shaft inundated by the tailings; tailings flow 45 km downstream
1974, Jun. 1	Deneen Mica, North Carolina, USA	?	mica	dam failure after heavy rain	38,000 m3	tailings released to an adjacent river
1973	(unidentified), Southwestern USA	?	copper	dam failure from increased pore pressure during construction of incremental raise	170,000 m3	tailings traveled 25 km downstream
1972, Feb. 26	Buffalo Creek, West Virginia, USA	Pittston Coal	coal	collapse of tailings dam after heavy rain (view Citizens' Commission report)	500,000 m3	the tailings traveled 27 km downstream, 125 people lost their lives, 500 homes were destroyed. Property and highway damage exceeded $65 million. (see details)
1971, Dec. 3	Fort Meade, Florida, USA	Cities Service Co.	phosphate	Clay pond dam failure, cause unknown	9 million m3 of clay water	tailings traveled 120 km downstream with Peace River, large fish kill
1970	Mufulira, Zambia	?	copper	liquefaction of tailings, flowing into underground workings	some 1 million tons	89 miners killed

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1970	Maggie Pie, United Kingdom	?	china clay	dam failure after raising the embankment and after heavy rain	15,000 m3	tailings spilled 35 meters downstream
1969 or earlier	Bilbao, Spain	?	?	dam failure (liquefaction) after heavy rain	115,000 m3	major downstream damage and loss of life
1968	Hokkaido, Japan	?	?	dam failure (liquefaction) during earthquake	90,000 m3	tailings traveled 150 meters downstream
1967, Mar.	Fort Meade, Florida, USA	Mobil Chemical	phosphate	dam failure, no details available	250,000 m3 of phosphatic clay slimes, 1.8 million m3 of water	spill reaches Peace River, fish kill reported
1967	(unidentified), United Kingdom	?	coal	dam failure during regrading operations	?	tailings flow covered an area of 4 hectares
1966	(unidentified), East Texas, USA	?	gypsum	dam failure	76,000 - 130,000 m3 of gypsum	flow slide traveled 300 meters; no fatalities
1966	Derbyshire, United Kingdom	?	coal	dam failure from foundation failure	30,000 m3	tailings traveled 100 meters downstream
1966, Oct. 21	Aberfan, Wales, United Kingdom	Merthyr Vale Colliery	coal	dam failure (liquefaction) from heavy rain	162,000 m3	the tailings traveled 600 meters, 144 people were killed (view details, watch video)

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1966, May 1	Mir mine, Sgorigrad, Bulgaria	?	lead, zinc, copper, silver, (uranium?)	dam failure from rising pond level after heavy rains and/or failure of diversion channel	450,000 m3	the tailings wave traveled 8 km to the city of Vratza and destroyed half of Sgorigrad village 1 km downstream, killing 488 people. (View details · historic photographs)
1965, Mar. 28	Bellavista, Chile	?	copper	dam failure during earthquake	70,000 m3	tailings traveled 800 meters downstream
1965, Mar. 28	Cerro Negro No.3, Chile	?	copper	dam failure during earthquake	85,000 m3	tailings traveled 5 km downstream
1965, Mar. 28	El Cobre New Dam, Chile	?	copper	dam failure (liquefaction) during earthquake	350,000 m3	tailings traveled 12 km downstream, destroyed the town of El Cobre and killed more than 200 people
1965, Mar. 28	El Cobre Old Dam, Chile	?	copper	dam failure (liquefaction) during earthquake	1.9 million m3	
1965, Mar. 28	La Patagua New Dam, Chile	?	copper	dam failure (liquefaction) during earthquake	35,000 m3	tailings traveled 5 km downstream
1965, Mar. 28	Los Maquis, Chile	?	copper	dam failure (liquefaction) during earthquake	21,000 m3	tailings traveled 5 km downstream

Table E-1. Historic Information on World -Wide Dam Failures [Hard rock mines highlighted]

	Location	Parent company	Ore type	Type of Incident	Release	Impacts
1965	Tymawr, United Kingdom	?	coal	dam failure from overtopping	?	tailings traveled 700 meters downstream, causing considerable damage
1962	(unidentified), Peru	?	?	dam failure (liquefaction) during earthquake and after heavy rainfall	?	?
1961	Tymawr, United Kingdom	?	coal	dam failure, no details available	?	tailings traveled 800 meters downstream

tonnes = metric tonnes

Sources:

- **Tailings Dam Incidents**, U.S. Committee on Large Dams - USCOLD, Denver, Colorado, ISBN 1-884575-03-X, 1994, 82 pages *[compilation and analysis of 185 tailings dam incidents]*
- **Environmental and Safety Incidents concerning Tailings Dams at Mines**: Results of a Survey for the years 1980-1996 by Mining Journal Research Services; a report prepared for United Nations Environment Programme, Industry and Environment, Paris, 1996, 129 pages *[compilation of 37 tailings dam incidents]*
- **Tailings Dams - Risk of Dangerous Occurrences, Lessons learnt from practical experiences**, Bulletin 121, Published by United Nations Environmental Programme (UNEP) Division of Technology, Industry and Economics (DTIE) and International Commission on Large Dams (ICOLD), Paris 2001, 144 p. *[compilation of 221 tailings dam incidents mainly from the above two publications, and examples of effective remedial measures]*

APPENDIX F

Tailings Dam Failure Runout and Volume Estimates

From: Rico, Benito and Diez-Herrero: Floods from tailings dam failures. J.Hazard.Mat 154(2008).

Potential Tailings Outflow Volume = V_f

V_T = Total Volume of the Tailings

Eq. 7: $V_f = 0.354 \times V_T^{1.01}$

V_T in millions (10^6) in cubic meters = 2,064 ← Enter number Here

V_f = Potential Tailings Outflow Volume

V_f = **788.6** V_f in millions (10^6) cubic meters

The above equation shows, that in average, one-third of the tailings and water at the decant pond is released during dam failures. The envelope curve (not included here) represents the maximum tailings volume that can be released in the most extreme situation in which pond volume was emptied following the dam break, as is the case of water-storage dam accidents or those of industrial (diluted) waste ponds.

D_{max} = Outflow Runout Distance

Eq. 5: $Dmax = 1.61 \times (HV_F)^{0.66}$

Dam Height in meters (H) = 225 ← Enter number Here

D_{max}	=	**4,690**	Outflow Distance in Kilometers
	=	**2,914**	Outflow Distance in Miles

conversion factors:

1 kilometer	=	0.621371	statute miles
1 foot	=	0.3048	meters
1 cubic yard	=	0.764555	cubic meters

Proposed Mine Tailings Dam Information

From: 2006 Water Rights Applications

TSF A

(Pebble Project Tailings Impoundment A, Initial Application Report (Ref. No. VA101-176/16-13), Knight Piesold Ltd, September 5, 2006)

Dam Height

"On-going staged expansion of the north embankment will result in a final height of 700 feet. The southeast and southwest embankments will be developed to heights of 710 feet and 740 feet, respectively." (Knight Piesold, p. 14 of 24)

Southwest Embankment (South Fork Koktuli) = 740 feet = 225 meters
Southeast Embankment (South Fork Koktuli) = 710 feet = 216 meters
North Embankment (South Fork Koktuli) = 700 feet = 213 meters

Waste Volume

"The design basis for the TSF at Site A will allow for secure storage of approximately 2 billion tons of tailings solids..." (Knight Piesold, p. 1 of 24)

TSF Total Storage Volume (tailings & waste rock) = 2.7 billion cubic yards (Knight Piesold, Figure 5.3)

Volume (yd^3)	Volume (m^3)
2.70E+09	2.06E+09

TSF G

(Pebble Project Tailings Impoundment G, Initial Application Report (Ref. No. VA101-176/16-13), Knight Piesold Ltd, September 5, 2006)

Dam Height

"On-going staged expansion of the north embankment will result in a final height of 700 feet. The southeast and southwest embankments will be developed to heights of 710 feet and 740 feet, respectively." (Knight Piesold, p. 14 of 24)

Main Embankment (Unnamed Tributary NK1.190 to the North Fork Koktuli River) = 450 feet = 137 meters

Saddle Dam (Unnamed Tributary NK1.190 to the North Fork Koktuli River) = 175 feet = 53 meters

Waste Volume

"The design basis for the TSF at Site G will allow for secure storage of approximately 500 million tons of tailings solids discharged into an engineered containment impoundment." (Knight Piesold, p. 1 of 24)

TSF Total Storage Volume (tailings & waste rock) = 580 million cubic yards (Knight Piesold, Figure 5.3)

Volume (yd^3)	Volume (m^3)
5.80E+08	4.43E+08

Ultimate Mine Buildout

10.78 billion tonnes	=	13.5 bcy for the total waste storage requirement, based on the average waste density implied by TSF A and TSF G of 59 lbs per cubic foot. This "average density" is derived from comparing the ratio of the amount of tailings in TSF A & G (Knight Pieslod, 2006) to the waste volume (Knight Pielsod, 2006, Appendix A). We had to use this approach since Knight Piesold did not disclose the waste rock volume weight or volume to be added to the impoundments in the applications, but the volume figures taken from the TSF A & G Appendices A did include both tailings and waste rock.
	=	10.32 billion cubic meters
10.78 billion tons	=	8.78 bcy at an average density of 100 pounds per cubic foot (this does not consider waste rock)
	=	6.72 billion cubic meters